International Journal of Mechanical Engineering and Technology (IJMET)
Volume 7, Issue 1, Jan-Feb 2016, pp. 214-224, Article ID: IJMET_07_01_022
Available online at
http://www.iaeme.com/IJMET/issues.asp?JType=IJMET&VType=7&IType=1
Journal Impact Factor (2016): 9.2286 (Calculated by GISI) www.jifactor.com
ISSN Print: 0976-6340 and ISSN Online: 0976-6359

FREE CONVECTION FROM OPTIMUM SINUSOIDAL SURFACE EXPOSED TO VERTICAL VIBRATIONS

Prof. Dr. Zena K. Kadhim
Mechanical Engineering, University of Wasit, Kut City, Iraq

Hadi O. Mery
Mechanical Engineering, University of Wasit, Kut City, Iraq

ABSTRACT

This paper presents a numerical study of the effect of forced vibrations on the heat transfer coefficient from sinusoidal surface by using ANSYS Fluent 15.0 program, besides a theoretical investigation to calculate the optimization of the amplitude to wavelength ratio of the sinusoidal surface. The physical model of the test surface can be presented as a copper plate having a sinusoidal upper surface, when it is heated by constant heat flux ranging as (250, 500, 750, 100, 1250 and 1500 w/m$^{2)}$ and vibrating with a range of frequencies (5, 10, 15, 20 and 25 Hz) including different vibration amplitude (3, 4 and 5 mm). This study is conducted for three different positions of test section: horizontal, vertical and downward heating inside air enclosure. The vibration parameters is defined to the ANSYS Fluent as user define function and this study is performed for three different positions of sinusoidal surface: horizontal, vertical and facing downward. This study concluded that the influence of vibration generally enhances the heat transfer coefficient and the vibrational mean Nesselt number (Nuv_{mean}), where they gain (9.5%) increasing in the horizontal position, (7.5%) increasing in the vertical position and (5.8%) increasing in the facing downward position due to vibrations existence. According to the current investigation, the vibrational mean Nesselt number depends on the Rayleigh number, applied frequency and the positions of the sinusoidal surface.

Key words: Free Convection, Heating Downward, Influence of Vibration on Heat Transfer, Optimum Sinusoidal Surface, Vibrational Reynolds Number

Cite this Article: Prof. Dr. Zena K. Kadhim and Hadi O. Mery. Free Convection From Optimum Sinusoidal Surface Exposed To Vertical Vibrations, *International Journal of Mechanical Engineering and Technology*, 7(1), 2016, pp. 214-224.
http://www.iaeme.com/currentissue.asp?JType=IJMET&VType=7&IType=1

GENERAL TERMS

Nu_{mean}: the mean Nusselt number

Re_{v}: vibrational Reynolds number

Nuv_{mean}: vibrational mean Nesselt number

Ra: Rayleigh number

V: sinusoidal vibrational velocity (m/s)

f: Vibration frequency (Hz)

a_v: vibrational amplitude (m)

Pr: Prantl number

hvx: vibrational local heat transfer coefficient ($W/m^2.$℃)

π: pi (π =3.14)

x is the amplitude to wavelength ratio

Whereas X and Y: Cartesian coordinates

t is the instantly time

1. INTRODUCTION

In recent years, there has been increased interest in the effects of vibrations on heat transfer. These studies are conducted because most industrial applications involve systems with some degree of relative vibration or pulsation of the fluid and the surface. Other investigators, however, have studied the problem with the object of increasing the heat transfer rate. As a result, vibration effect led to increase the rate of heat transfer, because the vibrations help to penetrate the boundary layer of fluid that is in contact with the vibrating surface and as a result, the rate of heat transfer increases from the thermal exchange surface [1].

In the laminar boundary layer, The vibrations of heated surface give rise to the turbulence and when the turbulent flow has a greater value of heat transfer rate than the laminar flow, then the vibration increases the heat transfer rate. Besides, most vibrated devices and mechanical machines are exposed to two types of vibrations, either temporary vibration, which fades after the effected force, is demised or continuous harmonic vibration [2].

The study of free convection heat transfer from the surfaces with complex geometry has received considerable attention due to its practical applications. The corrugated surfaces are encountered in many applications such as flat plate solar collectors, electronic cooling and flat plate evaporators in refrigerators and the sinusoidal wavy surface encompasses all other roughened surfaces and can be viewed as an approximation to many practical geometries for which free convection heat transfer is of interest [3].

1.1. Problem Statement

In a practical case, devices in a system are always under dynamic situation due to the operation of the system, which results in the devices being unavoidably subject to a vibrational motion. To validate the effect of the vibration motion on the structure or the heat transfer rate of the devices, then becomes an urgent need for the design of precise and effective devices takes the effect of vibration into account.

As the vibration is a considerable factor in the heated surfaces, then the vibration frequency, the vibration amplitude, the shape of the surface and the orientation of the heated surface are another considerable factor may determine the amount of the influence of vibration.

In the most published literatures, the majority of information focused on the effect of vibration frequency and amplitude on the heat transfer from the flat surfaces in the facing upward heat direction, where **Bhavnan et al** [4], 1991, presented an experimental study of the natural convection heat transfer from the sinusoidal wavy surface on vertical plates which showed that the heat transfer is increased (maximum increase) by about (15%) at an amplitude to wavelength ratio of (0.3) compared with the flat plate. The influence of vibration on heat transfer is conducted for many test geometries but the corrugated plate is appeared in the study of **M. A. Saleh** [5], 2006, for V-shaped grooves and square-shaped grooves where this experiment shows that vibration is a powerful enhancement tool, the heat rate increasing more than 2.5 fold; while **Abdalhamid R. Sarhan** [6], 2013, conducted the investigation of the influence of vibration on the free convection from the longitudinally finned plate and he reported a good enhancement of heat transfer rate due to vibration's applying.

1.2. The Aim of Study

The proposed study aims to achieve numerical investigation and theoretical analysis of the influence of vibration on the heat transfer from the sinusoidal surface heating upward and downward in different positions with constant heat flux.

1.3. Scope of This Study

- Achievement a theoretical study to choose the optimum amplitude to wavelength ratio of the sinusoidal surface and the ablitity of manufacturing by wire-cutting machine in the Iraq.
- Employment the ANSYS Fluent 15.0 program to connect the structural conditions (the vibration) into the thermal boundary conditions.
- Simulate the study of the influence of vibration on the heat transfer coefficient from the sinusoidal surface by using ANSYS-Fluent 15.0 program.

2. NUMERICAL SOLUTION

Extensive numerical analysis is employed to simulate the heat exchange between corrugated surface heated by constant heat flux, vibrating with sinusoidal velocity and the surrounding stagnant air in a closed room the geometry is sketched by Mechanical SolidWorks program and saving as IGES format, then it is exported to ANSYS 15.0 to read it then be ready for meshing and other activities.

2.1. Boundary Conditions

Corrugated surface enclosed by air enclosure is set to simulate the test section inside a closed room, all the faces of the enclosure, consider out of the thermal boundary layer with the constant temperature condition equal to the ambient temperature T_∞ Whereas the sinusoidal surface is exposed to constant heat flux and sine-wave vibrational movement where a file is programmed in C++ language to represent the sinusoidal vibrational motion, then it is interpreted to Fluent program as user define function in the velocity field of boundary conditions set up. The sinusoidal vibrational velocity profile is represented as [7]:

$$V = 2\pi * f * a_v \cos(2\pi f * t) \quad \textbf{(1)}$$

The corrugated surface is set as wall condition with two cases, either stationary wall in case of absence of vibration or moving the wall by user define function in case of existence of vibration. Same approach, the general solver is set to steady state in case of non-vibration and set to transient state in case of vibration existence.

In general, these boundary conditions are constant and governing all cases of this study except the case of user define function which is changing with each change of frequency or amplitude of the vibration according to the above equation. The boundary conditions set up and the method of using the user defines functions are shown in the Fig (1).

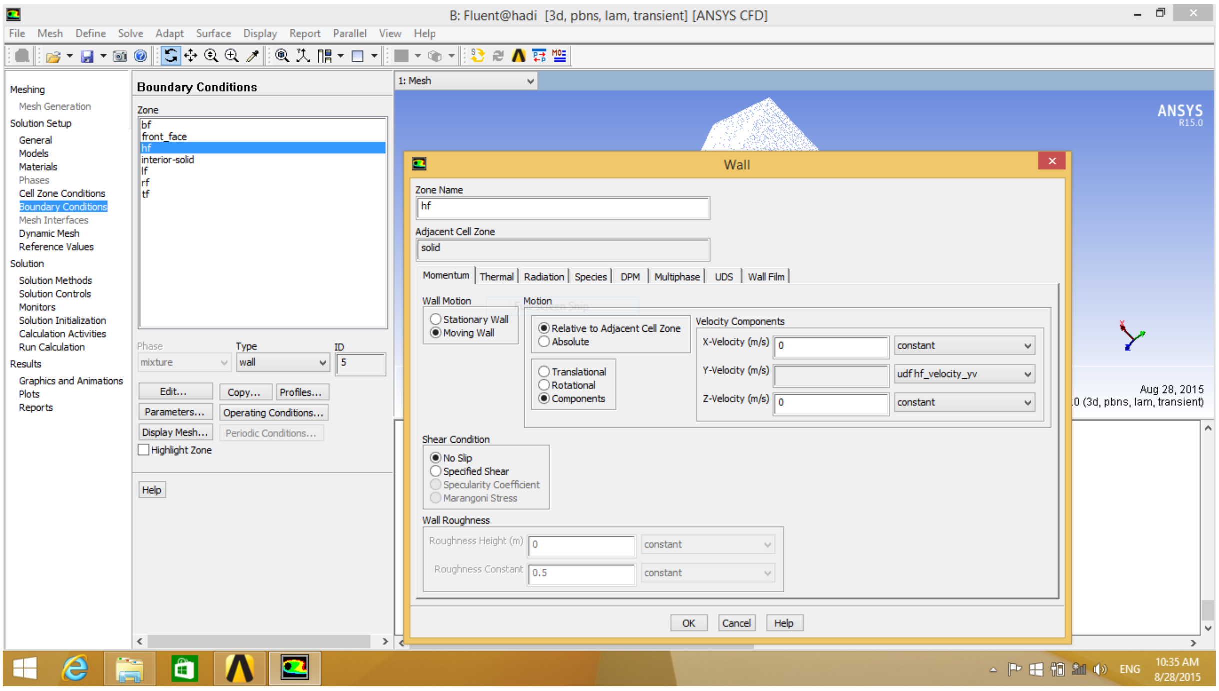

Figure 1 The boundary condition set up

3. RESULTS AND DISCUSSION

The numerical calculations have included two tracks to discussion: the first topic is investigating of the optimum corrugation profile of the test section surface, while the second topic is simulating of the experimental results in the ANSYS-Fluent program.

3.1. Corrugation Optimization

Numerical study has been achieved to select the optimum corrugation profile, where sinusoidal surfaces with different amplitude to wavelength ratios have been

investigated; graphical representation of the linear programming method [8], is adopted to choose the optimum value.

There are two independent variables to control the optimization, which is the amplitude (a) to wavelength (l) ratio denoted by x and the temperature of the corrugated surface denoted by T and subjected to the following constraints:

1. The higher heat transfer coefficient is required, which is resulting from a minimum surface temperature (T).
2. The possibility of manufacturing which depends on the machine's ability to implement the work in a good performance, which subjected to wavelength as $l \geq 8\,mm$ as well as the thickness (t) of the copper plate should be $t \geq 6\,mm$ because the machine needs 2mm in each side to hold the plate in addition to at least 2mm as a work area.
3. The availability of material dimensions, when the copper plate with high thickness isn't available in the local market of Iraq so the availability of the material is restricted to $t \leq 10\,mm$.

The mathematical modeling of these constraints as follows:

From item (1), the constraint can be yield is

$T = the\ minum\ possible\ value$ (Constraint-1)

From items (2 & 3) the following inequalities can be concluded:

$l \geq 8$

$t \geq 6$

$t \leq 10$

From item (2) it is also concluded that $t \geq 2a + 4$

Substituting t by a in the inequalities above to become

$l \geq 8$

$a \leq 3$

$a \geq 1$

Where $x = \frac{a}{l}$ as mentioned before, so the inequalities above can be rewritten in term of x to yield:

$x \leq \frac{3}{8}$ (Constraint-2)

$x \geq 0$ (Constraint-3)

These three constraints are employed in the fig (2) to show the optimum value of x there are four eligible values of x which are

$x = 0.1$

$x = 0.2$

$x = 0.3$

$x = 0.4$

This graphical representation assumed the $X-axis$ represents the amplitude to wave length ratio (x), while $Y-axis$ represents the average temperature (T) of the corrugated surface.

The temperature distribution decreases when the ratio of the amplitude to wavelength is increased, resulting to the increasing of the surface area which is reversely proportional to the temperature difference. The Fig (2) illustrates the graphical representation of the effect of constraints on each value of the corrugation profile (x) and finding the feasible domain which is achieved under the straight line of the corrugation ratio $x = 0.3$ that represents the optimum value to give a higher heat transfer coefficient in accordance with the reference [4], as well as it has possibility to manufacturing in the Iraq by wire cutting machine.

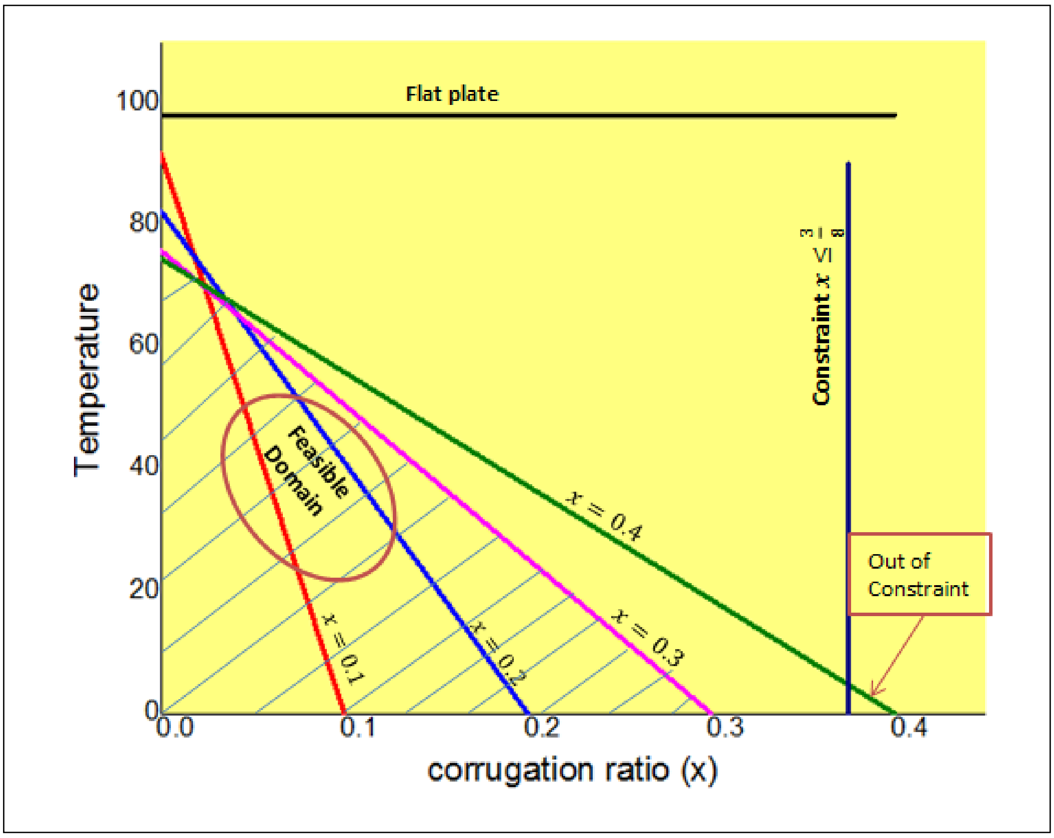

Figure 2 The graphical optimization method to choose the optimum corrugation ratio

3.2. Vibration's Absence Results

Figures (3 and 4) show the surface heat transfer coefficient of applying (1000 W/m^2) heat flux for the horizontal and vertical positions. It can be observed the surface heat transfer coefficient has a sinusoidal profile in both figures. In the horizontal position, the surface heat transfer coefficient is relatively higher than that of vertical position as well as the central points have a surface heat transfer coefficient is relatively less than that of side points because it has relatively higher temperatures and the surface heat transfer coefficient is inversely proportional to the temperature gradient.

3.3. Vibration's Existence Results

Figures (5, 6 and 7) show the surface heat transfer coefficient of applying (15 Hz) frequency and (1000 W/m^2) heat flux for the horizontal, vertical and facing downward positions. It can be noticed the surface heat transfer coefficient has a sinusoidal profile for the three positions as well as it has the highest value at the horizontal position and the lowest value at the facing downward position because of the buoyancy force and heat flux directions are coincided each other in the horizontal position, while they have opposite directions in the facing down position.

Fig (8) illustrates the vibrational mean Nesselt number with the applied frequencies of the horizontal, vertical and facing downward position and for all applied heat flux. It can be noticed that the vibrational mean Nesselt number increases when the applied frequency is increased for the three positions as well as the vibrational mean Nesselt number in the horizontal position is higher than that of vertical position that is in turn higher than that of facing downward position.

3.4. Comparison with Previous Studies

Fig (9) represents a comparison between this study and Saleh study reference [5] for the mean Nusselt number (Nuv_{mean}), where Saleh study deals with the effect of vibrating V- grooved impingement plate on heat transfer by forced convection from the heated air jet. The comparison is achieved of the following conditions for Saleh study, where the Reynolds number (Re=1700), vibration amplitude $(a_v) = 10\ mm$ and frequency range (from 10 to 25 Hz). Fig (9) clarifies that the mean Nusselt number is high proportional increased when the Nesselt number increased until 15 in both studies while it witnesses a significant difference beyond 15 Hz where the Nuv_{mean} of present study shows very little increasing in contrast of Salah study, which keeps on the same behavior (high proportional increase) and these may be attributed to the high value of vibration amplitude of Salah study, which is being more effective in high frequency range as well as Saleh study is applied for forced convection conditions which is originally turbulent and applying high frequency cause a significant increase in the flow turbulence leads to increase the rejected heat transfer.

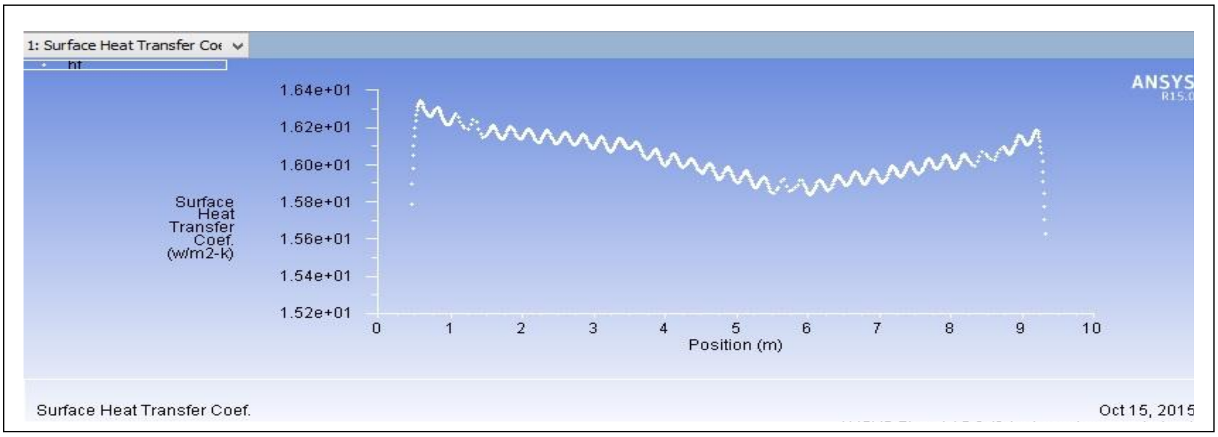

Figure 3 The surface heat transfer coefficient for non- vibrational case in the horizontal position.

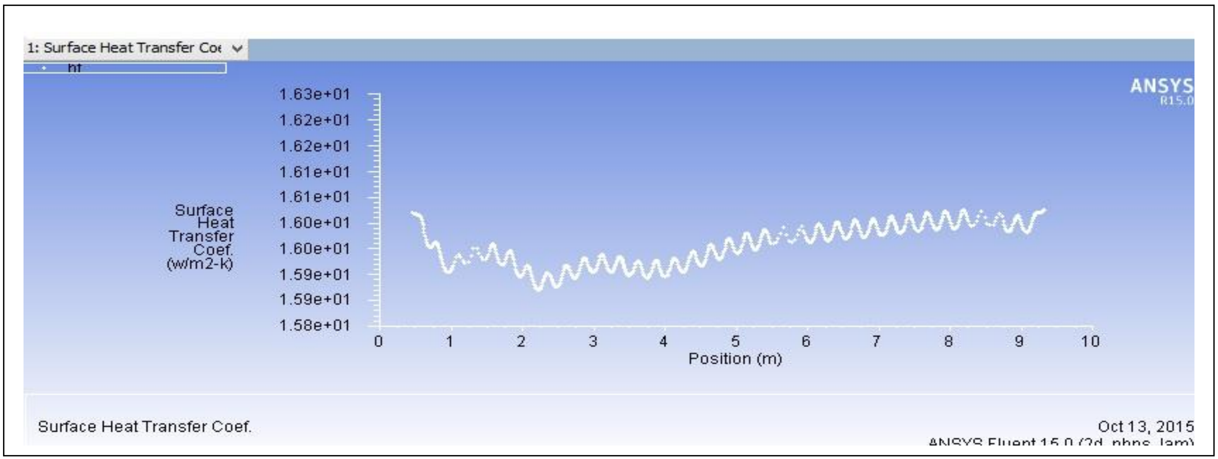

Figure 4 The surface heat transfer coefficient for non- vibrational case in the vertical position.

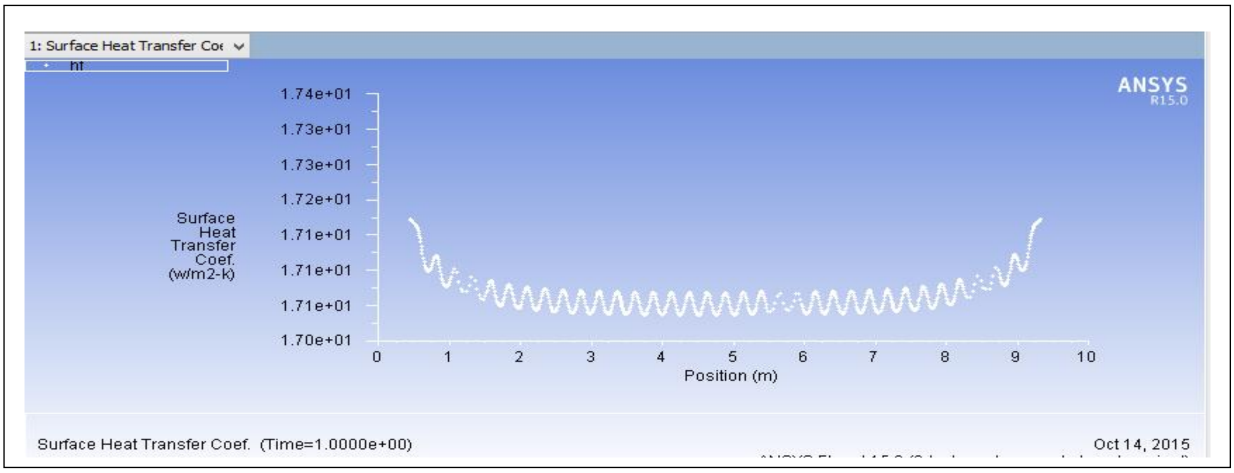

Figure 5 The surface heat transfer coefficient for 15Hz vibrational case in the horizontal position.

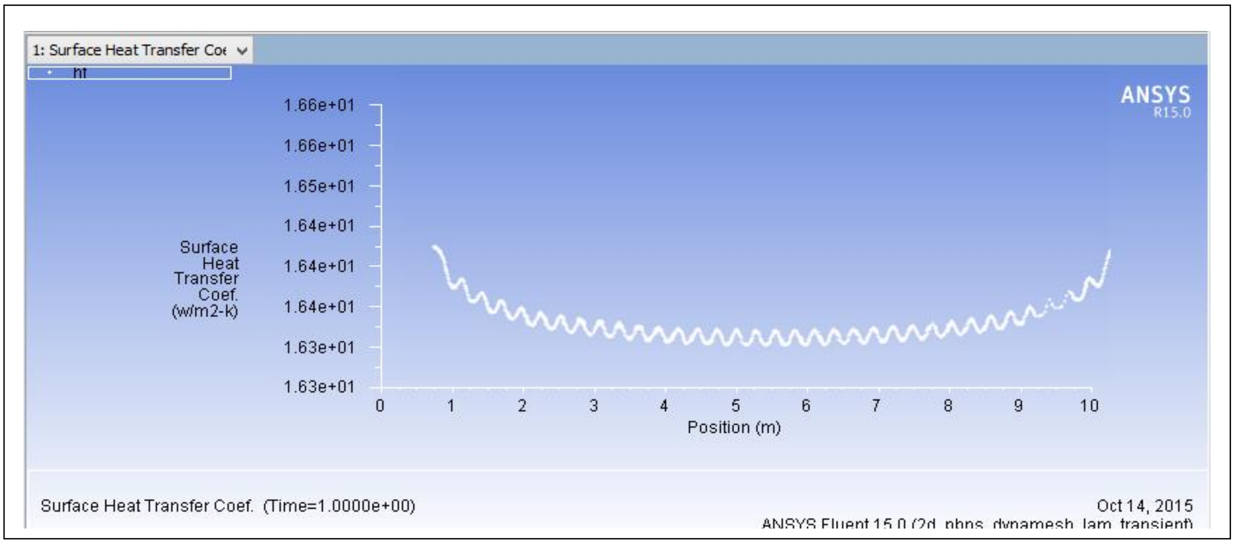

Figure 6 The surface heat transfer coefficient for 15Hz vibrational case in the vertical position

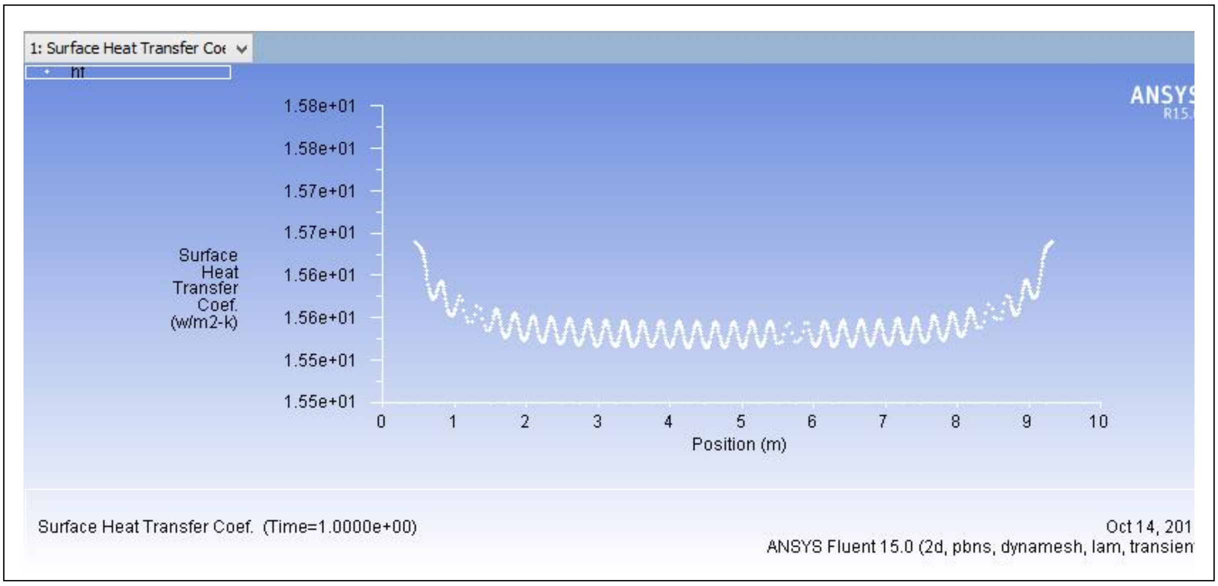

Figure 7 Explains the surface heat transfer coefficient for 15Hz vibrational case in the facing downward positions.

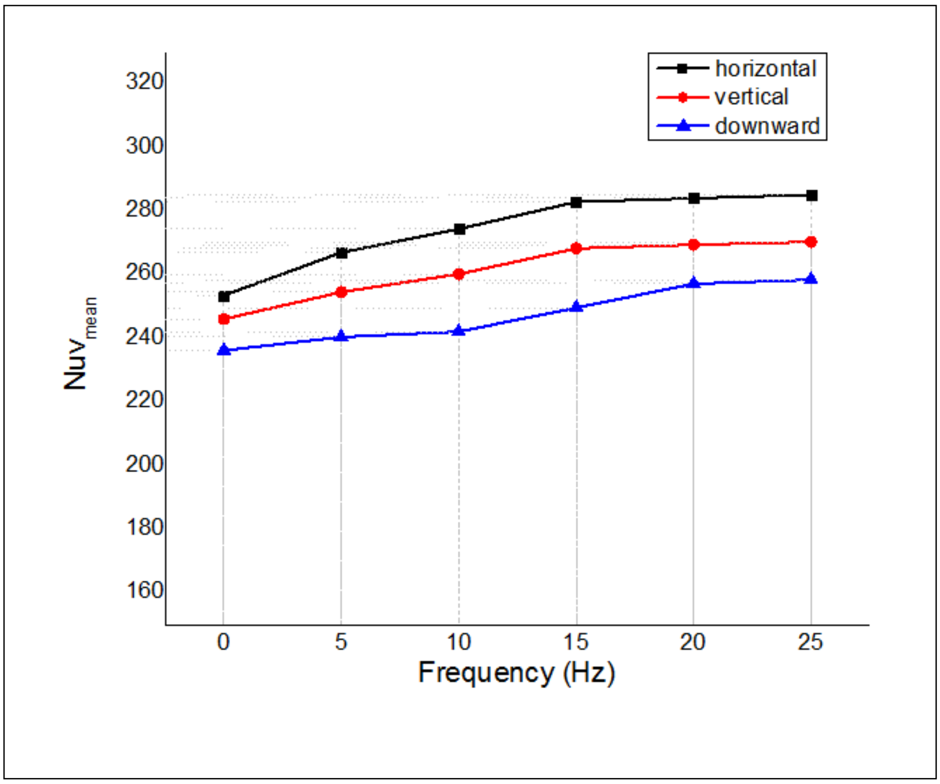

Figure 8 The vibrational Nesselt number of all applied frequencies and for the horizontal, vertical and downward positions.

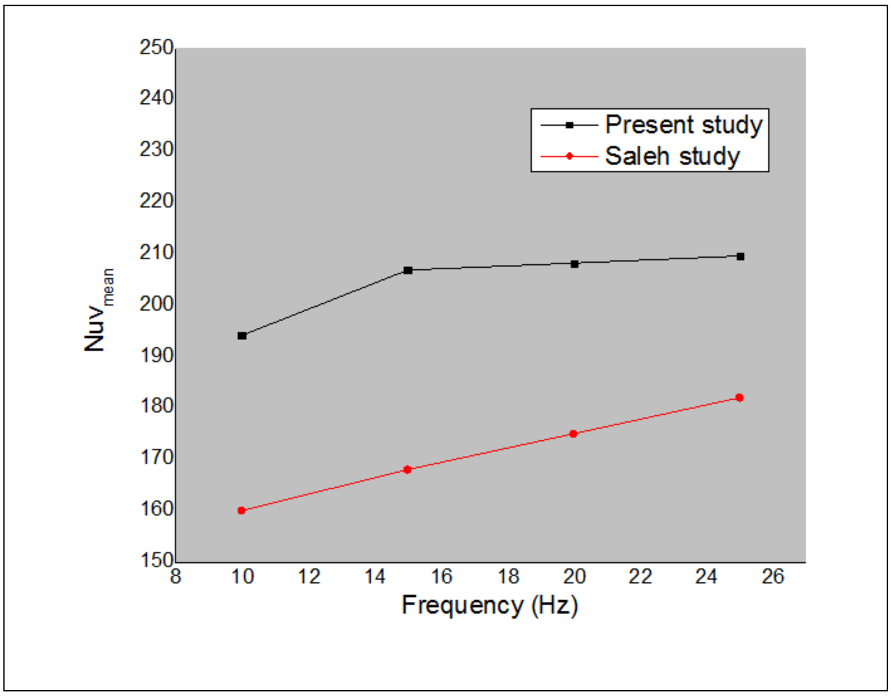

Figure 9 Comparison the present study with Saleh study.

4. CONCLUSION

- The vibrational mean Nesselt number (Nuv_{mean}) increases when the vibration amplitude is increased in all investigated cases.
- The vibrational Nesselt number increases when the applied frequency is generally increased, but the amount of this increasing depending on the position of the sinusoidal surface.
- In the horizontal and vertical positions, the lower ranges (5, 10, 15 Hz) of the applied frequency have a powerful enhancement on the vibrational mean Nesselt number; while the higher ranges (20 and 25 Hz) have an insignificant influence on the Nuv_{mean}.
- In the facing downward position, the higher ranges of the applied frequency have a powerful influence on the Nuv_{mean}; while the lower range of frequency have a little influence on the value of Nuv_{mean}.
- The vibrational mean Nesselt number generally increases, when the Rayleigh number is increased for all ranges of the vibrational Reynolds and for all positions.
- The total heat transfer coefficient depends on the ratio of the amplitude to wavelength of the sinusoidal surface, where the heat transfer coefficient increases proportional to this ratio and the sinusoidal surface of this study has an optimum ratio is 0.3.

There are some extensions of the present study as well as some new recommendations that are advised to conduct in future studies such as: study the influence of vibration on the forced convection heat transfer from pipes, cylinder and sphere and study the effect of the acoustic vibration on the heat transfer and compared with a vibrated plate at the same conditions.

5. ACKNOWLEDGEMENTS

We would express our thanks and appreciations to the dean of engineering college Dr. Ali Nassir Hillo and all member of engineering college of university of Wasit, great thanks goes to Eng. Ahmed Kamal to his help.

REFERENCES

[1] Hameed Abdulaali Jaber, 1981, *Effect of horizontal mechanical vibrations on natural convection heat transfer coefficient from a horizontal cylinder,* MSc. Thesis, March, 1981, university of Mosul, Iraq.

[2] Kenji Takahashi and Kazuo Endoh, (1990), *a new correlation method for the effect of vibration on forced convection heat transfer,* Journal of chemical engineering of Japan, Vol.23, No.1, pp.45-50.

[3] M. Ashjaee · M. Amiri ·J. Rostami, 2007, *A correlation for free convection heat transfer from vertical wavy surfaces"*, published online, January 2007.

[4] S.H.Bhavnani, Auburn, Alabama and A.E. Bergles, 1991, *Natural convection heat transfer from sinusoidal wavy surface,* Springer-Verlag Vol.26, PP. (341-349),(1991).

[5] M. A. Saleh, 2006, *Enhancement of convective heat transfer on a flat plate by artificial roughness and vibration*, International Conference on Heat and Mass Transfer, Miami, Florida, USA, January 18-20, 2006 (pp69-77).

[6] A.Ramanan and P.Senthilkumar. Heat Transfer Characteristics and Exergy Study of R744/R1270 in A Smooth Horizontal Tube, *International Journal of Mechanical Engineering and Technology*, 4(4), 2013, pp. 166-170.

[7] Jawdat A. Yakoob and Ehsan F. Abbas. Experimental Investigation of Convection Heat Transfer For Laminar Flow In An Inclined Annulus, *International Journal of Mechanical Engineering and Technology*, 5(4), 2014, pp. 160-168.

[8] Abdalhamid R. Sarhan, 2013, *Vertical forced vibration effect on natural convective performance of longitudinal fin heat sinks*, Tikrit Journal of Engineering Sciences/Vol.20/No.2/March 2013, (60-69).

[9] Wu-Shung Fu and Chien-Ping Huang, 2008, *Limitation enhancement of a mixed convection by a vibrational heat surface in a vertical channel*, Heat Mass Transfer (2008) 44:717–725.

[10] Ewin Kreyszig, *Advanced Engineering Mathematics*, 9th Edition.